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SHORELINES

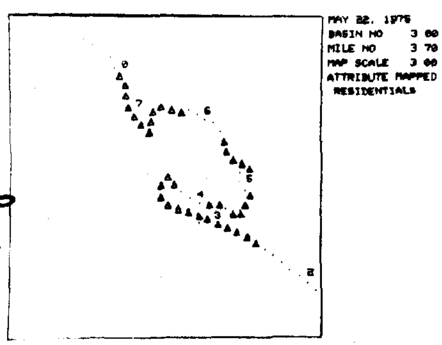
A COASTAL ZONE MANAGEMENT PROGRAM

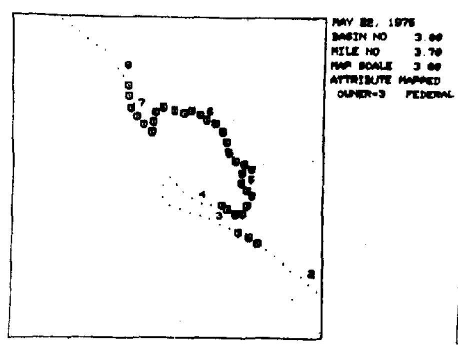
MAY 5 1976

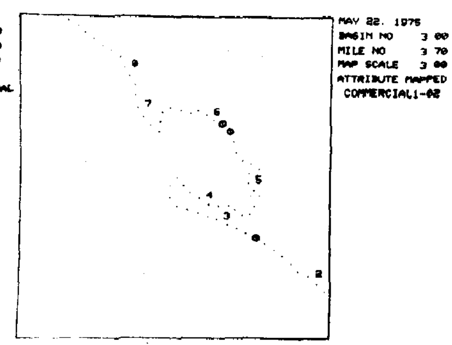
DESCRIPTION AND ANALYSIS OF A MACRO LAND USE MODEL (MACLUSE)

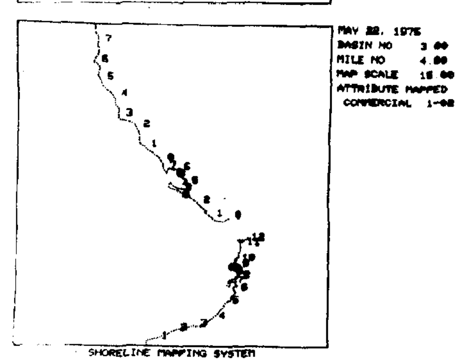
by

K. C. Swanson
R. P. Paquette









UNIVERSITY OF WASHINGTON
CENTER for QUANTITATIVE SCIENCE
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SH04

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June 1974

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TABLE OF CONTENTS

TABLES & GRAPHS

TABLE

GRAPH

Introduction

Land use decisions must be made continuously by local governments. Models have often been used to help determine the possible effects of alternative decisions. The purpose of this effort is to create a land-use model that would meet the needs of local jurisdictions faced with a variety of specific shorelines problems.

The Macro Land Use Model (MACLUSE) was developed to achieve this objective as quickly as possible. MACLUSE is a computerized system designed to describe the transfer of land among land-use categories through time. Eight categories were identified as basic to shorelines. Data for the model were derived from "experts" who are in a position to project the needs of a category into the future.

In this study three versions have been developed--the initial version and two subsequent modifications. Snohomish County is the geographic area covered by the analysis.

I. Program Elements

Table 1 describes the eight land-use categories which form the primary system variables (PSV's) of the model. The following criteria guided the selection of the eight land-use categories:

a) Choose categories which roughly corresponded to those used in the various county inventories, so that the existing data base can be most easily utilized.

b) Choose categories which would be meaningful in terms of planning land-management strategies. That is, categories which are considered important or significant to the people who will ultimately use the model to plan shoreline development.

c) Choose categories broad enough to include all possible land uses on a county's shoreline.

In modeling jargon, the primary system variables (PSV's) are the variables of primary interest in the system being simulated. The principle objective of the model, then, is to calculate values of the PSV's as a function of time, auxiliary variables, driving functions, and parameters of the model.

The auxiliary variables are functions of time and their values at a point in time depend on the current state of the system. The driving functions, on the other hand, are also

Table 1. Description of Primary System Variables.

Notation in MACLUSE	Acronym	Units	Definition
Primary System Variables			
V1	RES	miles	Residential - land platted for residential use (single and multiple units).
V2	REC	miles	Recreational - land sustaining non-private, high-density, recreational use.
V3	NAT	miles	Natural - land sustaining very low density, non-private use which seeks to maintain land in its natural state.
V4	CONR	miles	Conservancy and Rural - Farmland, open space, land used for renewable resources with little non-reversible change.
V5	SHDI	miles	Shoreline Dependent Industrial - any industry that must be located on the shoreline to function.
V6	SHDC	miles	Shoreline Dependent Commercial - any commercial operation that depends on a shoreline location to receive trade.
V7	TRANS	miles	Transshipment - any cargo loading, receiving or storage facility dealing with water traffic and located on the shoreline.
V8	NSHD	miles	Non-Shoreline Dependent Development - any development (industrial or commercial) that is not dependent on a shoreline location but may be located there all the same.

functions of time but depend on factors extrinsic to the system for their value at a point in time. The parameters are simply constants whose values are independent of the current state of the system. Table 2 lists the auxiliary variables, driving functions and the parameters used in the MACLUSE model.

II. Data Base

A. Initial values for the eight primary system variables were obtained from the Snohomish County Inventory Summary (January 1, 1973). These were considered to be the state of the system on January 1, 1973.

Since the categories used in the Inventory Summary did not correspond precisely to the eight MACLUSE categories, a rough correspondence in percentages between overlapping categories was determined in an interview with Mr. John E. Galt, Snohomish County Planning Department. The results are listed in Table 3.

B. Since the model was a preliminary effort designed to acquaint the authors with certain characteristics of shoreline models, data upon which projections are based were derived from the experts' "mental model" approach, the authors' intuition and an interaction matrix. The interaction matrix was developed from expert opinion in a brainstorming session at the University of Washington.

Table 2. Description of Auxiliary Variables, Driving Functions and Parameters

Notation in MACLUSE	Acronym	Units	Definition
Auxiliary Variables			
FLDD	FLDD	$	Dollar damage to RES, CONR, and NSHD as due to a 100 year flood.
PTI	PTI		Propensity to industrialize.
Driving Functions			
CPOP	CPOP	1000's	County population (Snohomish County).
SPOP	SPOP	1000's	Washington State population.
Parameters			
PTR	PTR		Propensity to recreate.
A	A	$/mile	Dollar per mile flood damage to CONR.
B	B	$/mile	Dollar per mile flood damage to NSHD.
C	C	$/mile	Dollar per mile flood damage to RES.
NT			Number of time periods over which model is run.
NCOM			Number of primary system variables.
Y1			Initial time point (year).

Table 3. Version III, Example 1, Projected Residential Change

Snohomish County Inventory Category	Shoreline Length in Miles	Percentage Correspondence to MACLUSE Categories
Residential	143.36	RES (100%)
Commercial	6.72	SHDC (80%), NSHD (20%)
Industrial	40.83	TRANS (10%), SHDI (20%), NSHD (70%)
Service	.78	NSHD (100%)
Recreational	26.55	REC (100%)
Circulation	52.02	NSHD (100%)
Utilities	11.33	NSHD (100%)
Agriculture	176.53	CONR (100%)
Comm. Forest	347.96	CONR (100%)
Undeveloped	412.95	NAT (100%)
	1219.23	

C. Data on changes in the transshipment category over 5 years were obtained from Mr. Dennis Gregoire, a planner with the City of Everett (Engineering Department).

Year	Piers	Warehouse
1960-1972	890 ft.	450 ft.
1973	990 ft.	450 ft.

Based upon the "mental model" of a planner with the Seattle Port Commission the process used for projecting future changes is contingent upon historical trends. The implication is that future changes in transshipment (TRANS) are equal to the average of the changes in five previous years. Therefore, the above data was interpreted as a change of 100 ft. in five years or 20 ft. = .004 mile each year.

D. Data on amount of damage expected from a 100 year flood in Snohomish County were obtained from Mr. Bob Hamlin, Department of Emergency Services, Snohomish County.

River System	Total Damage $	Damage to Buildings (RES)		Damage to Agric. (CONR)		Damage to All Other (NSHD)	
Snohomish	16,980,000	35%	5,943,000	45%	7,641,000	20%	3,396,000
Stillaguamish	3,355,000	50%	1,677,500	39%	1,308,450	11%	369,050
Total	20,335,000		7,620,500		8,949,450		3,765,050

For Snohomish River, percentages were given as 26% - Agric. and 19% - Dikes, which were combined into the 45% figure shown.

These data were used to obtain dollar/mile damage coefficients for the 3 categories (Residential, Conservancy and Rural, and Non-Shoreline Dependent Development) in which flood damage is considered to occur.

E. Population statistics for Snohomish County and the State of Washington were obtained from the Washington State Bureau of Vital Statistics. Data obtained are tabled below.

Year	1970	1975	1990
Snohomish County	265,300	285,000	409,000
Washington State	3,427,200	3,925,800	5,445,100

A linear interpolation was performed to obtain population figures for intermediate years.

III. Basic Model Mechanisms

MACLUSE is designed to calculate new values for the primary system variable of past values, selected parameters and the driving functions. Thus, if $V_n(j)$ = value of n^{th} PSV at time j, then $V_n(j) = V_n(j-1)+\Delta V_n(j)$, where $\Delta V_n(j)$ is the change which occurred between time j-1 and time j. It was necessary as a first step to postulate which factors influence the values of the primary system variables at the current time point, as well as what factors influence the change in the primary system variables between the previous and the current time point. The potential affecting factors include both the values of the PSV's at the previous time point and the values of the changes in PSV's between previous time points.

The interaction matrix (see Table 4) is a convenient way of representing these postulations. The "affectees" are the current values of the PSV's (states at time J) and the changes in PSV's between the previous and current time points (changes between time (J-1) and time (J)). These head the columns of the matrix.

The "affectors" are the values of the PSV's at the previous time point (states at time J-1) and the changes in PSV's over the previous 6 years.

The matrix may be read as follows: for any category at the top of the matrix, look down the column beneath it. The X's indicate which factors are postulated to be those "interacting with" or influencing the value of the category. Note the interaction matrix says nothing about the exact form of the relationship between the category and its influencing or "interacting" factors. This information is provided by the equations of Table 5 for those factors influencing the changes in PSV's. The weight to be given to each influencing factor, as represented in the equations, was determined from expert opinion and intuition.

Returning to the general equation of the first paragraph, $V_n(j) = V_n(j-1)+\Delta V_n(j)$, it becomes apparent that the interaction matrix describes the same process (for example, RES(J) is influenced by RES(J-1) and ΔRES(J)). It further indicates which factors influence $\Delta V_n(j)$; an equation of Table 5 says how $\Delta V_n(j)$ is affected by these factors.

IV. Mathematical Constraints in the Model

The set of mathematical constraints in the model include:

1) The amount of land in any category must never become negative.
2) The sum of changes between categories in any one year (or unit time period) must be zero, i.e. total land amount should remain constant throughout the time period over which the model is run.
3) A particular type of land must not take land from itself, i.e. only transfers among different land

Table 4. Interaction Matrix

	affectees / affectors	Changes between time (J-1) and time J								States at time J									
		ΔRES(J)	ΔREC(J)	ΔNAT(J)	ΔCONR(J)	ΔSHDI(J)	ΔSHDC(J)	ΔTRANS(J)	ΔNSHD(J)	RES(J)	REC(J)	NAT(J)	CONR(J)	SHDI(J)	SHDC(J)	TRANS(J)	NSHD(J)		FLDD(J)
J-6 to J-5	ΔSHDC(J-5)						X												
	ΔTRANS(J-5)							X											
J-5 to J-4	ΔSHDC(J-4)						X												
	ΔTRANS(J-4)							X											
J-4 to J-3	ΔSHDC(J-3)						X												
	ΔTRANS(J-3)							X											
J-3 to J-2	ΔSHDC(J-2)						X												
	ΔTRANS(J-2)							X											
J-2 to J-1	ΔSHDC(J-1)						X												
	ΔTRANS(J-1)							X											
	ΔNSHD(J-1)								X										
	ΔREC(J-1)		X																
States at time J-1	RES(J-1)									X									X
	REC(J-1)										X								
	NAT(J-1)	X										X							
	CONR(J-1)	X											X						X
	SHDI(J-1)					X								X					
	SHDC(J-1)														X				
	TRANS(J-1)															X			
	NSHD(J-1)																X		X
	SPOP(J-1)		X																
	CPOP(J-1)	X	X						X										
Changes between time (J-1) and time J	ΔRES(J)				X	X				X									
	ΔREC(J)				X	X					X								
	ΔNAT(J)											X							
	ΔCONR(J)												X						
	ΔSHDI(J)													X					
	ΔSHDC(J)														X				
	ΔTRANS(J)															X			
	ΔNSHD(J)																X		
	ΔSPOP(J)		X																
	ΔCPOP(J)	X	X						X										
	PTI(J)				X	X													
	PTR(J)																		

Table 5. Equations used to describe changes in demand for 8 land-use categories.

PSV	Acronym	Equation for change in PSV for interval ending at time I (DV(I), I=1,NCOM)
V1	RES	$\Delta RES(I) = 5.*\frac{\Delta CPOP(I)}{CPOP(I-1)}*[NAT(I-1)+CONR(I-1)]$ if $\Delta CPOP(I)>0$; $= 0$ if $\Delta CPOP(I)<0$
V2	REC	$\Delta REC(I) = PTR*\ REC(I-1)*[\frac{CPOP(I)+\Delta CPOP(I)}{CPOP(I)}]*[\frac{SPOP(I)+\Delta SPOP(I)}{SPOP(I)}]$
V3	NAT	$\Delta NAT(I) = -(1/3*\Delta RES(I)+1/3*\Delta REC(I))$
V4	CONR	$\Delta CONR(I) = -(2/3*\Delta RES(I)+2/3*\Delta REC(I)+PTI)$
V5	SHDI	$\Delta SHDI(I) = -.01*SHDI(I-1)+PTI$
V6	SHDC	$\Delta SHDC(I) = 1/5*\sum_{J=I-5}^{I-1} \Delta SHDC(J)$
V7	TRANS	$\Delta TRANS(I) = 1/5*\sum_{J=I-5}^{I-1} \Delta TRANS(J)$
V8	NSHD	$\Delta NSHD(I) = .1*\Delta NSHD(I-1)*[\frac{CPOP(I)+\ CPOP(I)}{CPOP(I)}]^3$
	FLDD	$FLDD(I) = A*CONR(I-1)+B*NSHD(I-1)+C*RES(I-1)$
	PTI	$PTI = \frac{SPOP(I)-SPOP(I-1)}{SPOP(I-1)}*\Delta SHDI(I-1)$

use types are considered, not transfers within a single category.

4) Transfers of land may not occur from more expensive categories to less expensive categories.

5) If the least expensive transfer cannot satisfy the amount of land called for by the equation no further attempt is made to satisfy this demand by taking land from the next least expensive category.

How each successive version of the model satisfied, or did not satisfy, these constraints will be discussed in following sections. The fourth and fifth constraint were added upon evaluation of Version 2 of the model.

1. Version 1

A. Explanation of Mechanisms

The first version consists of a main program and four subroutines (INPUT, SOLVE, DIFF, ADD). The program flow and transfers in and out of the various subroutines is represented in flow chart I. Version I is fairly straightforward; only the standardization of the changes in the primary system variables referred to as $\Delta V (\Delta V_n)$ needs elaboration. This standardization is necessary due to the constraint to keep the total number of shoreline miles constant.

The standardization of the DV's in subroutine DIFF works as follows:

Let $V_n(i)$ = system variable n at time i.

$DV_n(i+1)$ = change in system variable n from time i to i+1 (not standardized)

Constraint (2) can be formulated for Snohomish County as

$$\sum_n V_n(i) = 1219. \text{ miles at any time } i$$

Then the standardized change is $DV_n^*(i+1)$, where

$$\sum_n (V_n(i)+DV_n(i+1)) = SUM$$

$$\frac{SUM}{1219.}(V_n(i)+DV_n(i+1) = G_n(i+1)$$

$$G_n(i+1)-V_n(i) = DV_n^*(i+1)$$

$$V_n(i+1) = V_n(i)+DV_n^*(i+1)$$

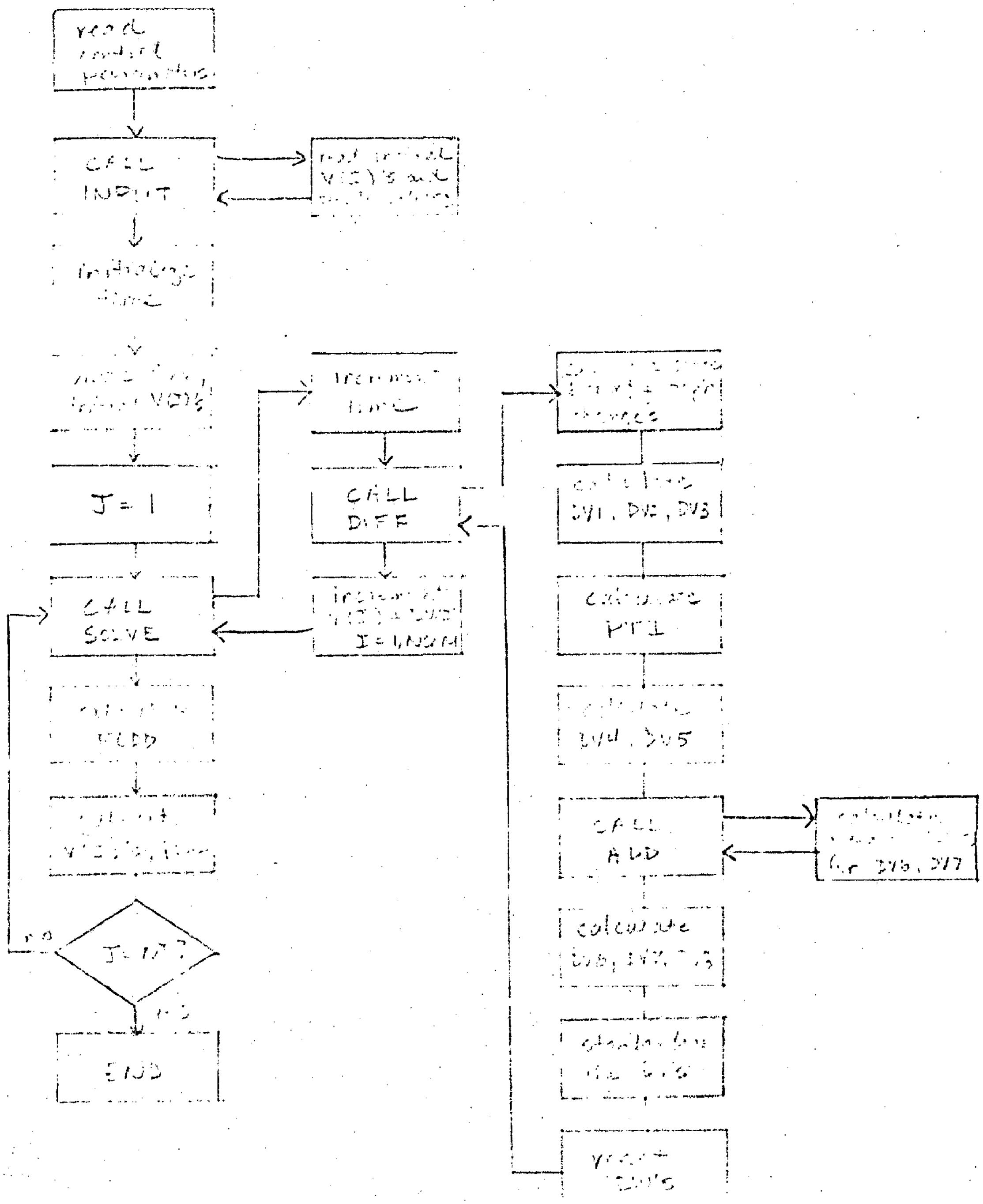
Then we also have $\sum_n V_n(i+1) = 1219.$ at time i+1

B. Problems with Version 1

The standardization package used in Version 1 satisfied constraint (2) of the model, but violated constraint (1). That is, land amount in some categories was allowed to go negative when $DV_n^*(i+1)$ was negative and greater in absolute value than $V_n(i)$.

Table 6.

Flow Chart I



2. Version 2

A. Explanation of Mechanisms

Changes in Version 1 incorporated into Version 2 are described below and illustrated in Flow Chart II.

1) Subroutine INPUT1, which reads a vector D of dollar values for each of the eight land-use categories and a matrix F of allowable land transfers. The elements of F are $f_{ij} = \begin{cases} 0 \text{ if land transfer not allowed from category } j \text{ to category } i \\ 1 \text{ if transfer is allowed} \end{cases}$

   By convention, all diagonal elements are zero. This satisfies constraint (3) of the model.
   If 1's occur on all off-diagonal elements, this implies a no-policy situation (all transfers are allowed).
   If 0's occur on off-diagonal elements, existence of policies preventing certain transfers from occurring is implied.

2) In subroutine DIFF, the standardization package is removed. For sake of clarity, it should be noted that the DV's calculated in DIFF do not represent final changes in PSV's; these are now calculated in subroutine DIFF2. Rather, the DV's in DIFF now represent demands for change in the eight categories; they indicate how much change each category would "want" to undergo between time points if there were no constraints to change.

3) For a particular land type, subroutine MATR chooses from the allowable transfers to that type the one which will in fact occur, based on economic constraints.

In effect, it chooses the least expensive of these allowable transfers. To do this for the i^{th} land type, it multiplies the i^{th} row times the vector D of dollar values, then chooses the smallest non-zero element of the resulting vector (which is the i^{th} row of matrix FF). This element is then assigned a new value which is either the amount of land available in the chosen donor category or the amount of land desired (calculated in DIFF), whichever is smaller. All other elements in the row are converted to zero. Thus, the i^{th} row of FF becomes the vector of actual land transfers into the i^{th} category.

After this is done for all rows, the FF matrix is complete except for the diagonal elements. These must reflect the land removed from each category. This is done by simply summing along a particular column of FF and assigning the negative of this sum to the diagonal element of that column.

4) Subroutine DIFF2 adds the losses and gains for each category determined in MATR. To do this, it simply sums across the rows of FF to get total changes for

Table 7. Flow Chart II

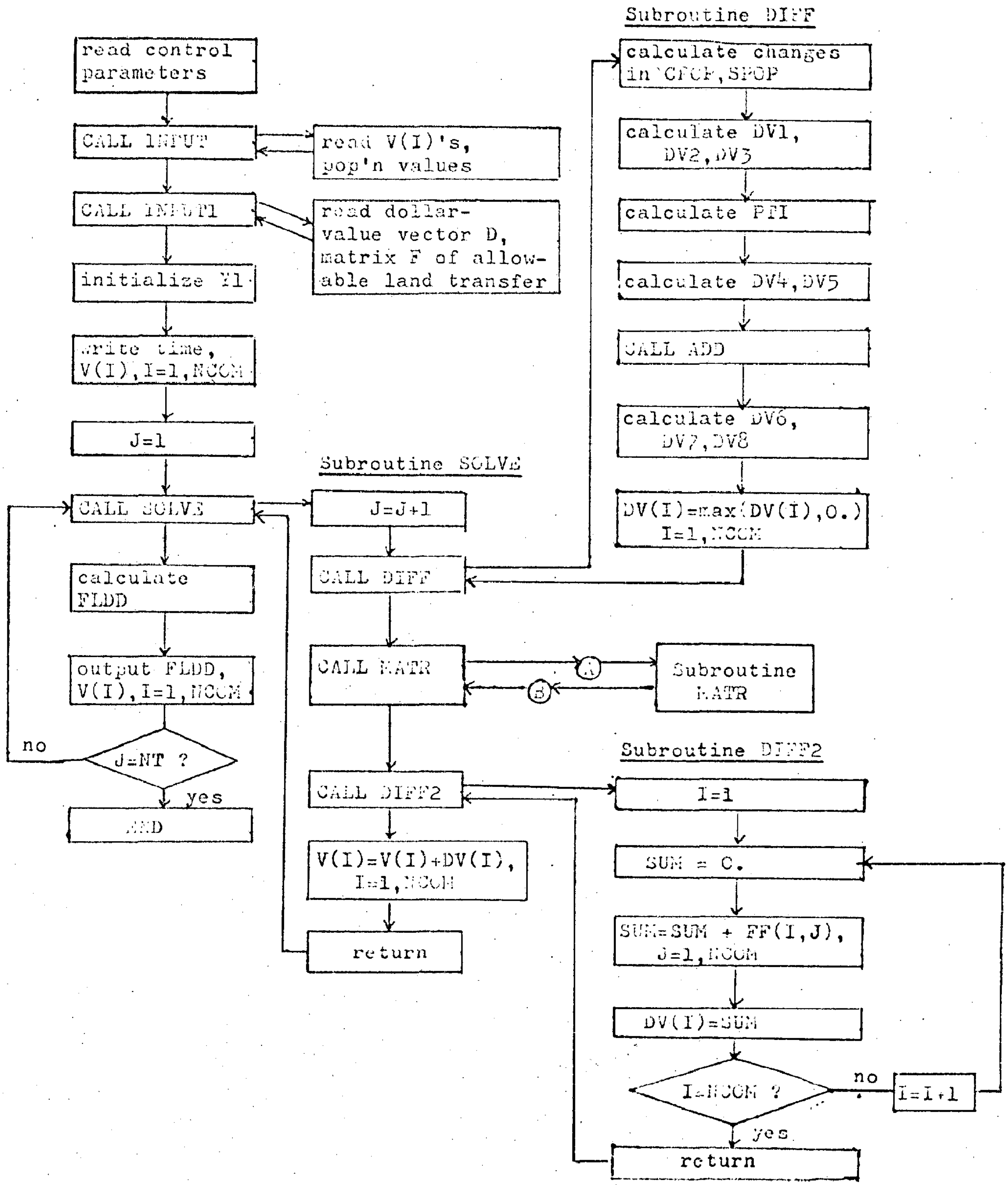
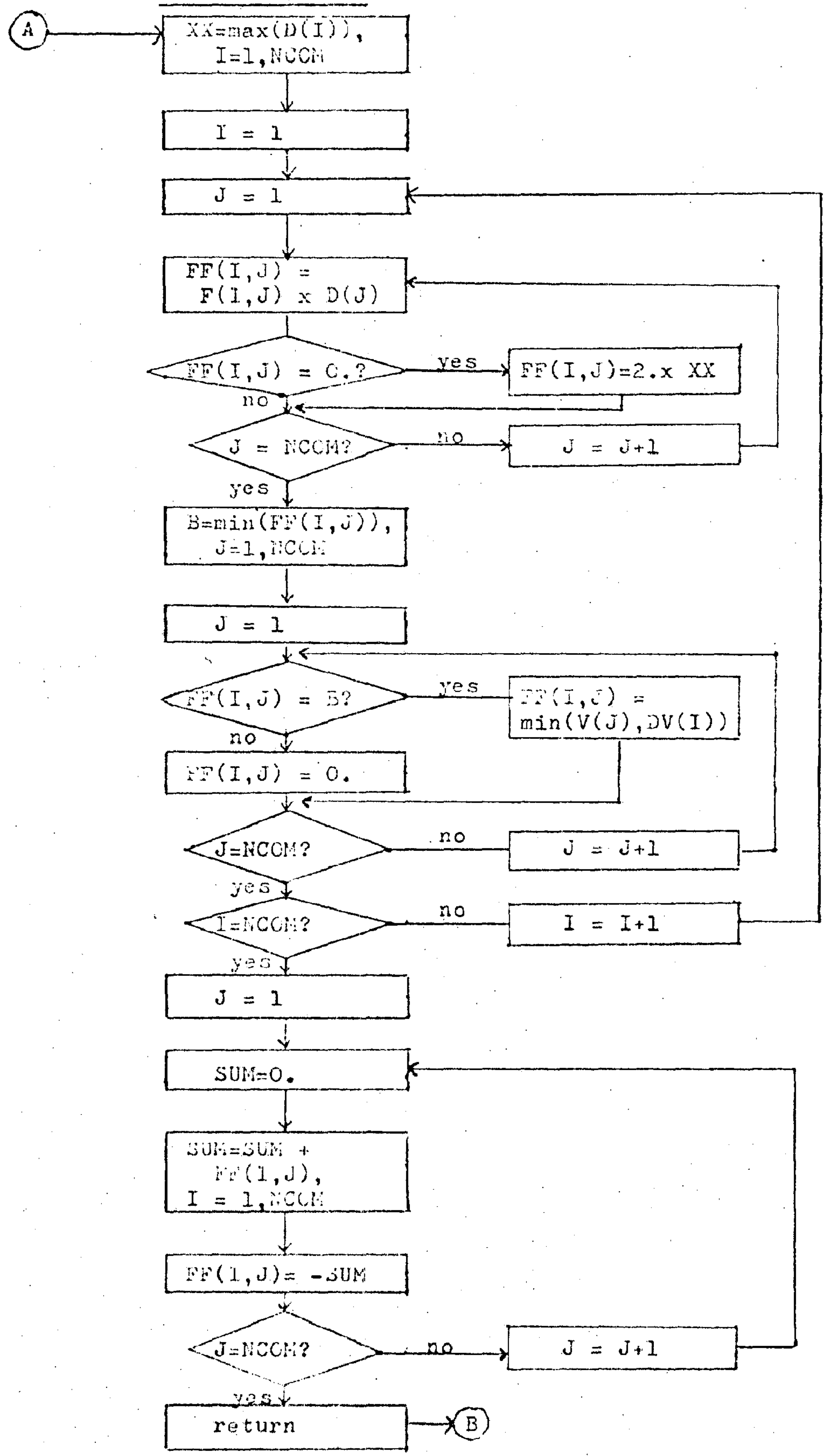


Table 7 (cont.)

Subroutine MATR



each row. These are the DV's, or final changes in PSV's between time points. In subroutine SOLVE these are added to the PSV's (V(I)'s) to get the new values for the PSV's.

B. Problems with Version 2

Version 2 satisfies constraint (2) by assigning a negative value to diagonal elements of FF, equal to land loss in each category. Thus, total land amount will stay constant.

It satisfies constraint (3) by making the diagonal elements of F equal to zero, i.e. a category cannot take land from itself.

It does not satisfy constraint (1). As land is taken from a category, the amount left in that category is not changed. Consequently, you can take more than is there, i.e. several land types can take the same amount of land from a category, driving it below zero.

Furthermore, Version 2 allows the transfer of land from more expensive to less expensive categories. This is unlikely to occur in the real world. Hence, a fourth constraint in the model would be that this is not allowed to occur.

Also, if the least expensive transfer cannot satisfy the land amount "wanted" by a category (i.e., for transfer from category j to category i, V(J)<DV(I)), then no further attempt is made to satisfy this demand by taking land from the next

least expensive category, etc. This should be added as a fifth constraint in the model.

C. Output from Version 2

Following is a copy of output from Version 2 for a 13-year run starting at 1973 as the initial time point (Y1).

Note (1) Input data values

State population projected statistics (SPOP) and county population projected statistics (CPOP) for Snohomish County are printed for the 13-year period. These are followed by the 1973 values for the eight primary system variables (vector V), the vector DV of tendencies to change as calculated in subroutine DIFF for 1973, and the matrix DW of changes in the five years preceding 1973 in the categories SHDC (V6) and TRANS (V7).

Note (2) Input values for dollar values and matrix

The dollar-value vector D for the eight categories is printed. These were arrived at by an arbitrary, intuitive ranking. They are followed by the matrix F, which indicates allowable land transfers. The columns and rows are ordered in the manner used throughout this documentation, i.e. RES, REC, NAT, CONR, SHDI, SHDC, TRANS, NSHD.

Thus, a "1" in F(3,4) indicates land transfer is allowed _from_ category 4 (CONR) _to_ category 3 (NAT). Choices for these values were also arbitrary at this stage.

Note (3) Output for 13-year run

Year 1 is the initial year (1973); note these values correspond to input data values for vector V. For years 2 through 14, values for vector V of the eight primary system variables are given, as well as a value for FLDD (dollar damage as due to a 100-year flood).

Note that negative values occurred in the NAT category, and also that it gained land although it is the least expensive category. These problems were discussed in the preceding section.

CALCULATION OF MILES OF SHORELINE BY CATEGORY

8 CATEGORIES CALC EVERY 1 YRS FROM YR $\underbrace{\text{1}}_{1973}$ FOR 13 YRS

(1) INPUT DATA VALUES

SPOP, CPOP, V, DV, DW

SPOP	3.7383E+06	3.8320E+06	3.9258E+06	4.0195E+06	4.1132E+06	
	4.2067E+06	4.3006E+06	4.3943E+06	4.4991E+06	4.6044E+06	
	4.7095E+06	4.8145E+06	4.9196E+06			
CPOP	2.6850E+05	2.7670E+05	2.8500E+05	2.9330E+05	3.0150E+05	
	3.0980E+05	3.1810E+05	3.2630E+05	3.3460E+05	3.4290E+05	
	3.5110E+05	3.5940E+05	3.6770E+05			
V	143.4	26.55	413.0	527.5	8.120	
	5.380	4.080	94.26			
DV	7.160	.9000	-0.	-0.	-0.	
	-0.	-0.	.9400			
DW	.1760	.1760	.1760	.1760	.1760	← SHDC
	4.0000E-03	4.0000E-03	4.0000E-03	4.0000E-03	4.0000E-03	← TRANS

(2) INPUT VALUES FOR DOLLAR VALUES AND MATRIX

D	15.00	10.00	1.000	10.00	19.00	18.00
	20.00	3.000				

F	-0	-0	1	1	-0	-0	-0	1	RES
	1	-0	1	1	-0	1	1	1	REC
	-0	1	-0	1	-0	-0	-0	-0	NAT
	-0	-0	1	-0	-0	-0	-0	-0	CONR
	1	-0	1	1	-0	1	1	1	SHDI
	1	-0	1	1	1	-0	1	1	SHDC
	1	-0	1	1	1	1	-0	1	TRANS
	-0	-0	-0	-0	1	1	-0	-0	NSHD

(3)

YR	RES	REC	NAT	CONR	SHDI	SHDC	TRANS	NSHD	FLDD
initial → 1	143.4	26.5	413.0	527.5	8.1	5.4	4.1	94.3	
2	287.0	27.7	268.1	527.5	8.1	5.4	4.2	94.4	25721150
3	410.0	29.1	143.4	527.5	8.1	5.5	4.2	94.4	32857872
4	510.6	31.0	40.7	527.5	8.1	5.7	4.3	94.4	38697972
5	551.3	33.3	-2.6	527.5	8.1	5.8	4.5	94.4	41061346
6	548.7	30.7	12.9	524.9	5.5	3.2	1.9	94.4	40885305
7	561.7	30.7	-.2	524.9	5.5	3.4	2.0	94.4	41635819
8	561.4	30.5	1.2	524.7	5.3	3.1	1.7	94.4	41619818
9	562.6	30.5	-.3	524.7	5.3	3.3	1.9	94.4	41688037
10	562.4	30.2	1.3	524.4	5.0	3.0	1.6	94.4	41670854
11	563.6	30.2	-.2	524.4	5.0	3.2	1.7	94.4	41744111
12	563.4	30.0	1.2	524.2	4.8	2.9	1.5	94.4	41727231
13	564.6	30.0	-.2	524.2	4.8	3.0	1.6	94.4	41799198

D. Analysis of Sample Output

From / To	F: RES	REC	NAT	CONR	SHDI	SHDC	TRANS	NSHD	DV (initial)	D
RES	0	0	1	1	0	0	0	1	7.16	15.0
REC	1	0	1	1	0	1	1	1	.9	10.0
NAT	0	1	0	1	0	0	0	0	0	1.0
CONR	0	0	1	0	0	0	0	0	0	10.0
SHDI	1	0	1	1	0	1	1	1	0	19.0
SHDC	1	0	1	1	1	0	1	1	0	18.0
TRANS	1	0	1	1	1	1	0	1	0	20.0
NSHD	0	0	0	0	1	1	0	0	.94	3.0

The policies reflected by this F-matrix and D-vector are as follows:

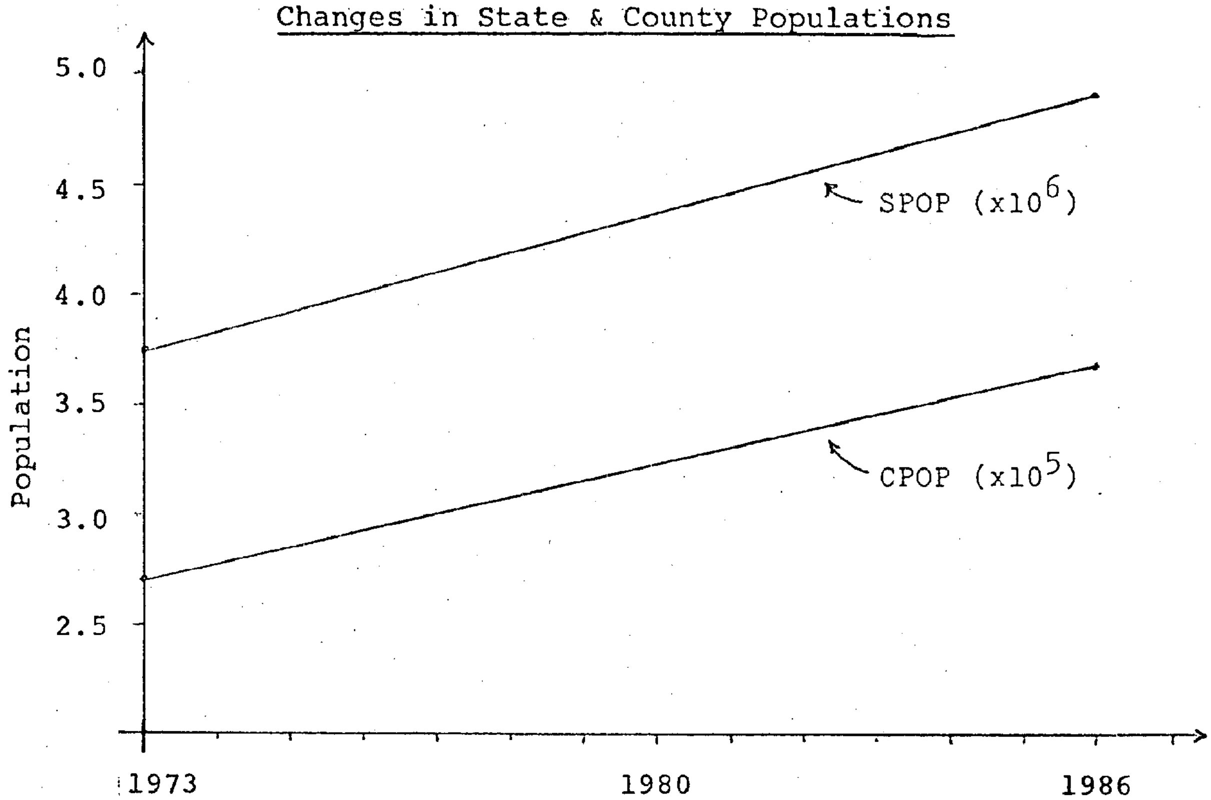
(1) Industrial categories are most favored (SHDI, SHDC, and TRANS) by both F and D

(2) NAT and CONR are least favored

(3) RES is more restricted than the industrial categories in the number of categories from which it is allowed to draw, but has a relatively high dollar-value rank

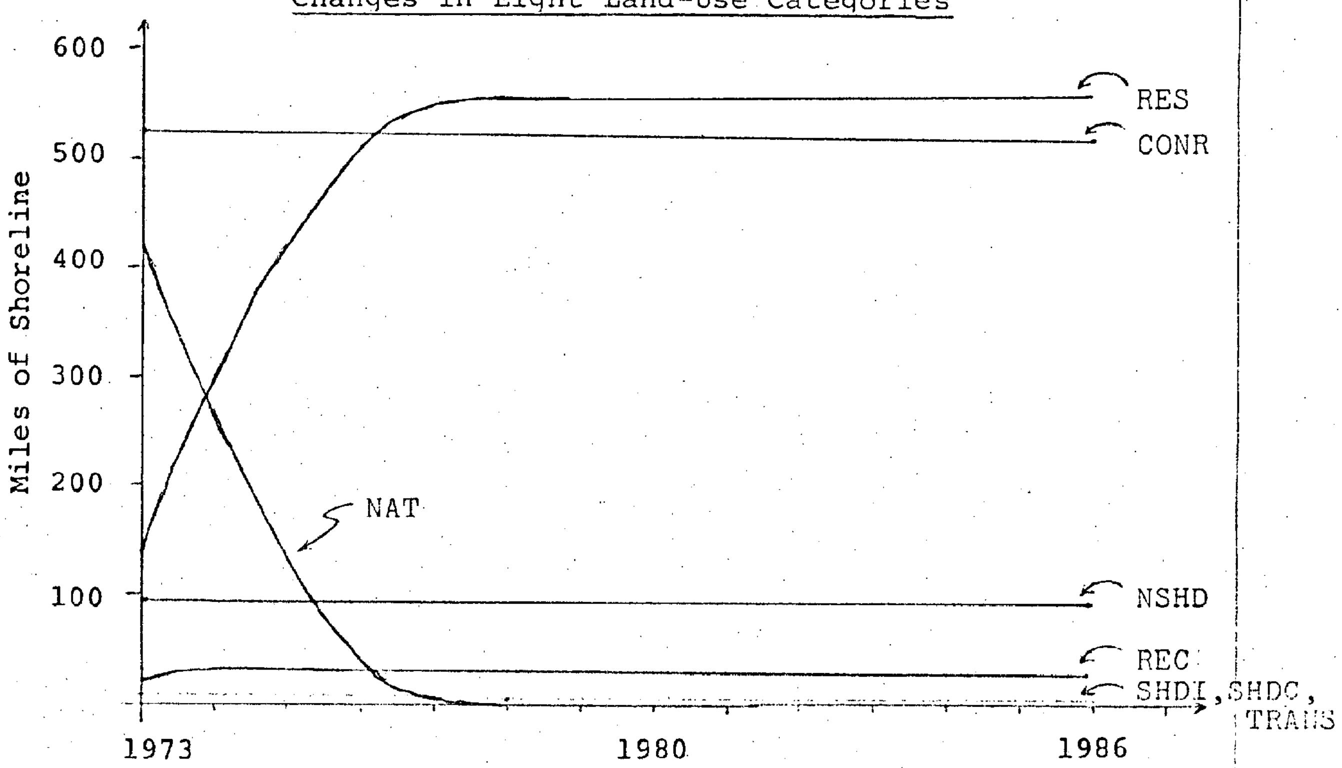
Graph 1

Changes in State & County Populations



Graph 2

Changes in Eight Land-Use Categories



The most drastic changes occurred in the RES and NAT categories. Note that the initial DV for RES was extremely high compared to the other categories and that the NAT category had an extremely low dollar-value ranking compared to the other categories from which RES could draw. Thus, the RES category had a very strong "pull" and would return to the NAT category each iteration to fulfill it's "desire" for land.

The other category that achieved any significant increase over the 13-year period was REC (3 miles). Note that this category had an initial DV of .9, considerably less than RES. It, too, would go first to NAT to draw land, thus increasing the drain on natural land.

NSHD was the only other category to increase, but only by one-tenth of a mile. It was also the only other category to have a positive initial DV (.94). It could draw from SHDI and SHDC, which partially accounts for their decrease.

All other categories had an initial DV of 0. Note that the industrial categories, all highly favored by the F policy matrix and the D dollar-value vector, all showed a steady decrease.

It thus appears that the DV vector (of "tendencies" to change based mainly on population changes) is of much greater significance than F or D (i.e. economic factors) in determining what changes actually occurred. This may indicate a need for revision of the basic model mechanisms.

3. Version 3

A. Modification of Version 2

Needed modifications to the model, as indicated in the discussion of problems with Version 2, were incorporated into Version 2. These included the following:

a) Land was ranked in ascending order by dollar value, and as a category made allowable land transfers to itself, it drew sequentially from these ranked categories until its "need" was satisfied;

b) A category was not allowed to draw land from a category more expensive than itself;

c) When land was drawn from a category, the amount left was adjusted to reflect the loss.

B. Output from Version 3

There are three examples of output produced by Version 3, each of which represents the outcome of the simulation of different land use policies. Each output contains a listing of initial input values followed by a table of land-use change in the eight categories over a thirteen-year time span. Those are followed by three analytical graphs, the first two of which depict how a single variable changes over time. The third depicts how variable 3 (natural land type) varies with variable 4 (conservatory--rural land). This graph shows the threshold nature of the relationship between the two variables.

1. The first example indicates what might happen if present policies (as controlled by the matrix of allowable transfers) are allowed to continue. The sample output and analytical graphs follow.

CALCULATION OF MILES OF SHORELINE BY CATEGORY

8 CATEGORIES CALC EVERY 1 YRS FROM YR 1973 FOR 13 YRS

Table 8

INPUT DATA

STATE AND COUNTY POPULATIONS

YEAR	STATE POP	COUNTY POP
1973	3738300	268500
1974	3832000	276700
1975	3925800	285000
1976	4019500	293300
1977	4113200	301500
1978	4206700	309800
1979	4300600	318100
1980	4394300	326300
1981	4499100	334600
1982	4604400	342900
1983	4709500	351100
1984	4814500	359400
1985	4919600	367700

INITIAL STATE VARIABLE VALUES

```
V-S: 143.4 26.5413.0527.5  8.1  5.4  4.1 94.3
DV-S:  7.2   .9 -0.0 -0.0 -0.0 -0.0 -0.0   .9
```

Table 9

RELATIVE DOLLAR VALUES AND ALLOWABLE TRANSFERS
CATEGORY

	RES	REC	NAT	CONR	SHDI	SHDC	TRAN	SHDG
($)	15	10	1	10	19	18	20	3
(1)	-0	-0	1	1	-0	-0	-0	1
(2)	1	-0	1	1	-0	1	1	1
(3)	-0	1	-0	1	-0	-0	-0	-0
(4)	-0	-0	1	-0	-0	-0	-0	-0
(5)	1	-0	1	1	-0	1	1	1
(6)	1	-0	1	1	1	-0	1	1
(7)	1	-0	1	1	1	1	-0	1
(8)	-0	-0	-0	-0	1	1	-0	-0

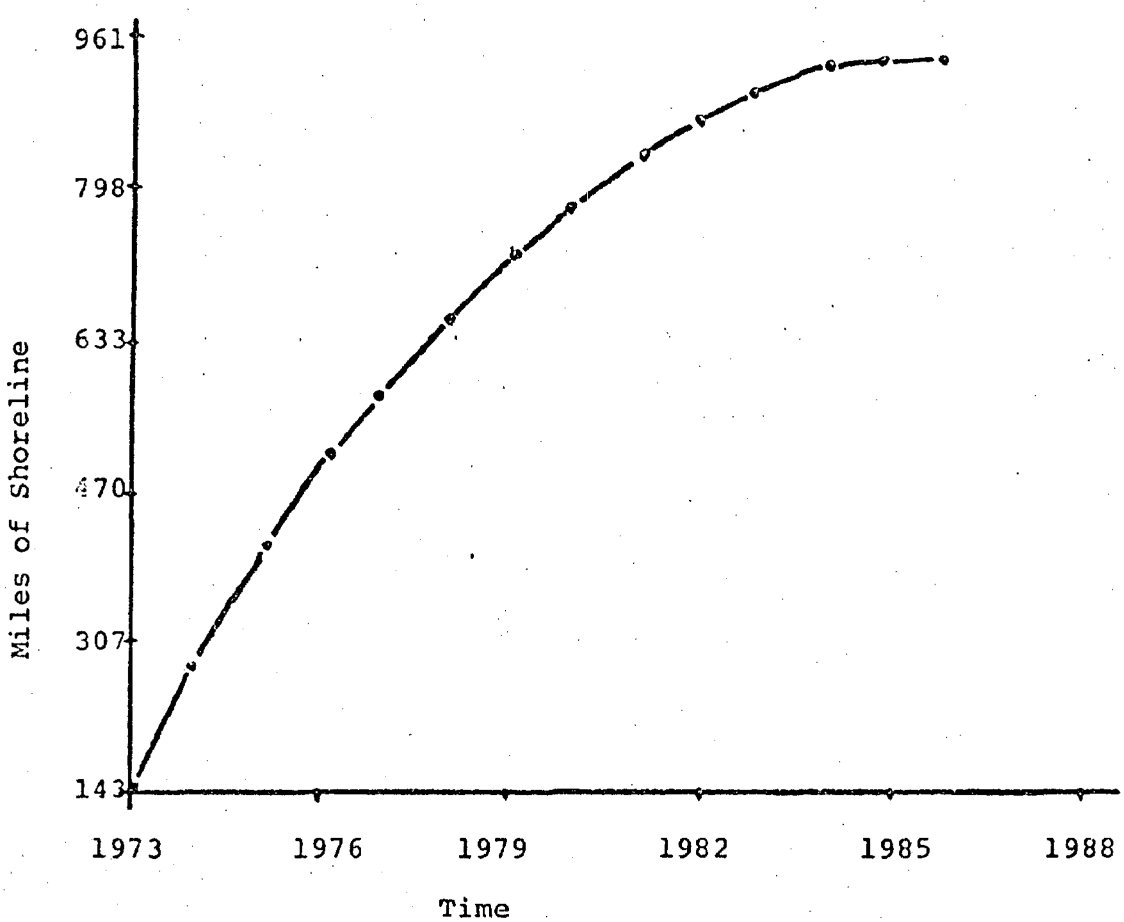
Table 10

THE OUTPUT GENERATED BY THIS PROGRAM CONSISTS
OF A TABLE PRESENTING VARIABLE VALUES THROUGH
TIME, AND ONE TO SEVERAL GRAPHS.

YEAR	RES	REC	NAT	CONR	SHDI	SHDC	TRANS	NSHD	FLOD
1973	143.4	26.5	413.0	527.5	8.1	5.4	4.1	94.3	
1974	287.0	27.7	268.1	527.5	8.1	5.5	4.2	94.3	25717276
1975	410.0	29.1	143.4	527.5	8.1	5.6	4.2	94.3	32853598
1976	510.6	31.0	40.7	527.5	8.1	5.8	4.3	94.3	38693657
1977	592.4	33.3	.0	527.5	8.1	5.9	4.5	50.7	41693612
1978	667.0	36.2	0.0	500.3	8.1	6.1	4.6	.0	43726981
1979	735.9	39.9	0.0	427.5	8.1	6.2	4.7	0.0	46993820
1980	792.4	44.5	0.0	366.1	8.1	6.3	4.8	0.0	49661147
1981	840.2	50.4	0.0	312.2	8.1	6.5	4.9	0.0	51892623
1982	879.9	57.8	0.0	264.9	8.1	6.6	5.0	0.0	53722318
1983	912.4	67.1	0.0	222.9	8.1	6.8	5.1	0.0	55184797
1984	939.3	78.7	0.0	184.0	8.1	6.9	5.2	0.0	56360230
1985	961.1	93.4	0.0	147.3	8.1	7.0	5.3	0.0	57254770
1986	961.1	111.0	0.0	129.5	8.1	7.2	5.4	0.0	57075888

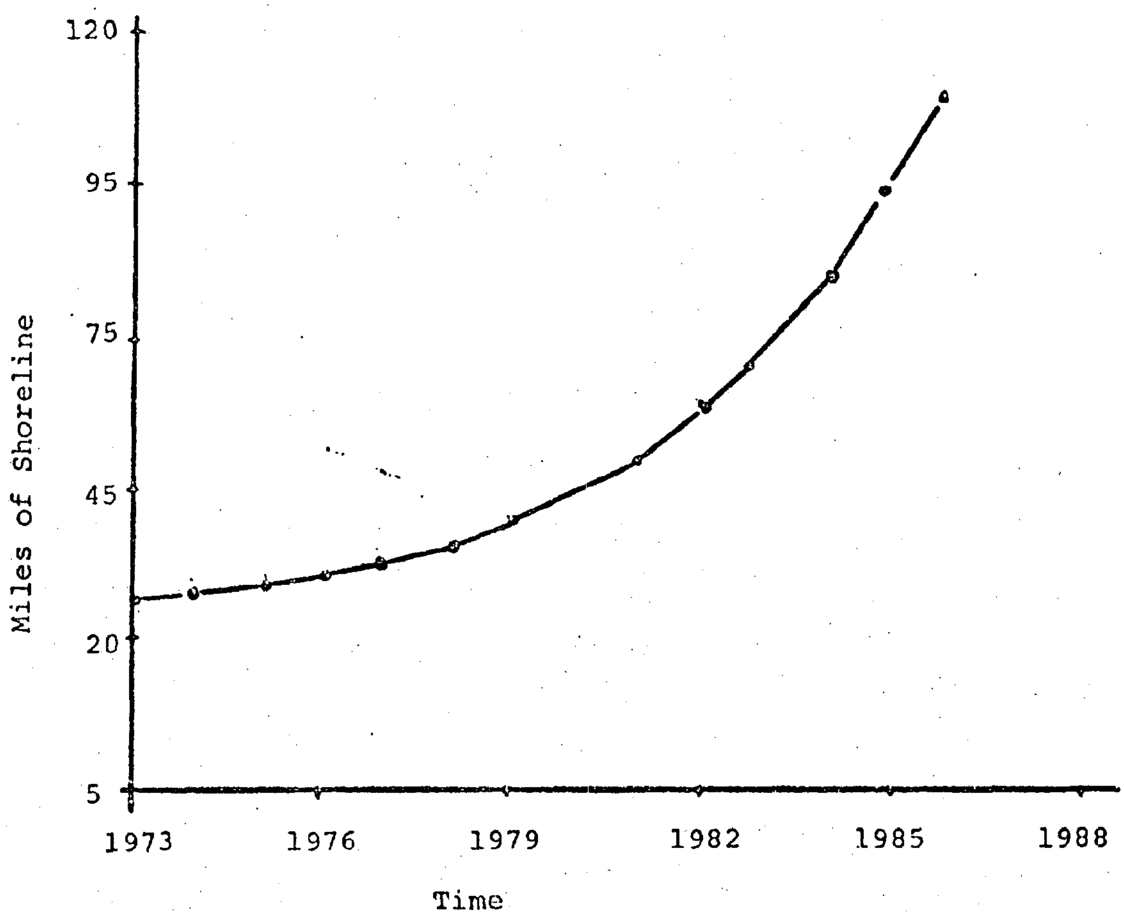
Graph 3

Projected Changes in Residential Use



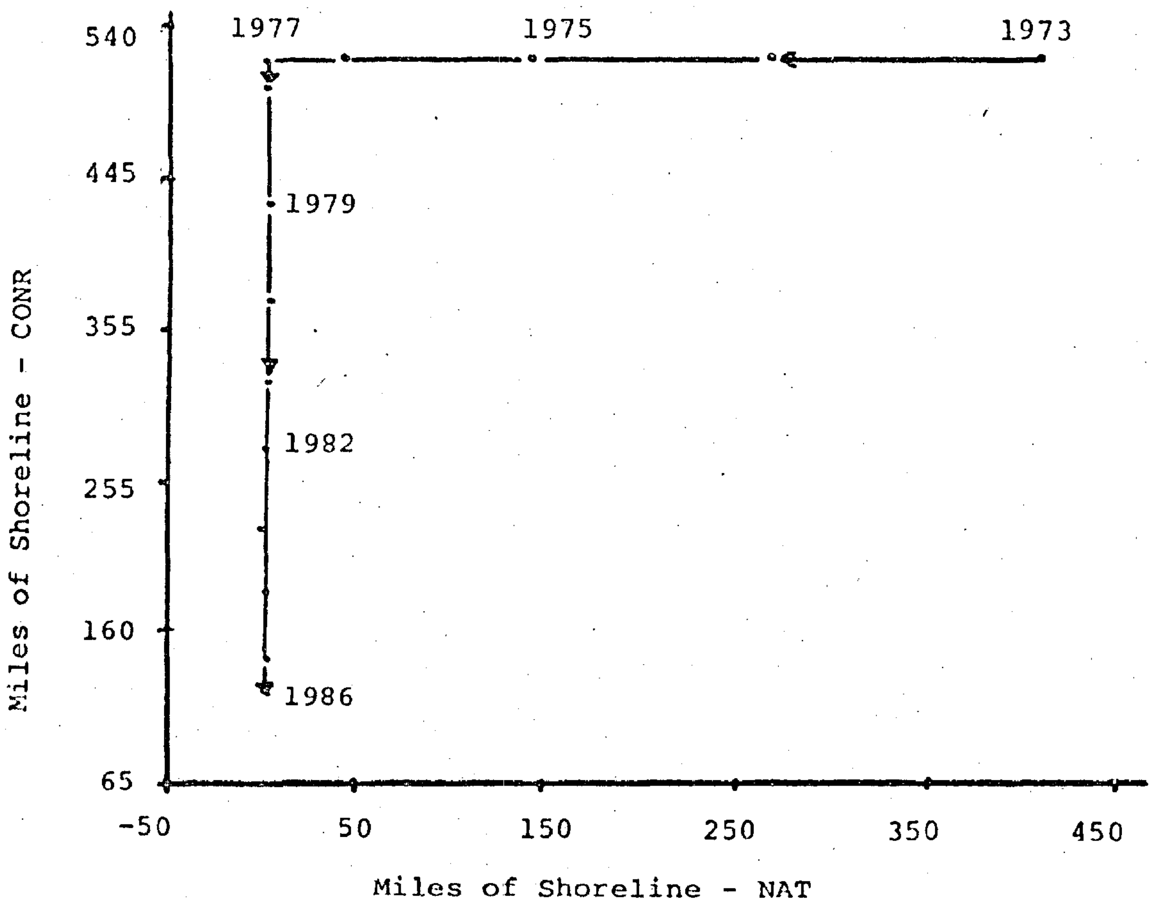
Graph 4

Projected Change in Recreational Use



Graph 5

Land Losses from NAT & CONR between
1973 & 1986



2. The second example is intended to represent a conservation approach. It differs from the first in that the transfer of NAT (natural land type) and CONR (conservancy--rural land type) into any other land category is severely restricted. The key aspects of this policy are: a) NAT land is allowed to transfer into CONR, b) CONR into REC (recreational type), and c) REC into NAT.

CALCULATION OF MILES OF SHORELINE BY CATEGORY

8 CATEGORIES CALC EVERY 1 YRS FROM YR 1973 FOR 13 YRS

Table 11

INPUT DATA

STATE AND COUNTY POPULATIONS

YEAR	STATE POP	COUNTY POP
1973	3738300	268500
1974	3832000	276700
1975	3925800	285000
1976	4019500	293300
1977	4113200	301500
1978	4206700	309800
1979	4300600	318100
1980	4394300	326300
1981	4499100	334600
1982	4604400	342900
1983	4709500	351100
1984	4814500	359400
1985	4919600	367700

INITIAL STATE VARIABLE VALUES

V-S:	143.4	26.54	13.05	27.5	8.1	5.4	4.1	94.3
DV-S:	7.2	.9	-0.0	-0.0	-0.0	-0.0	-0.0	.9

Table 12

RELATIVE DOLLAR VALUES AND ALLOWABLE TRANSFERS
CATEGORY

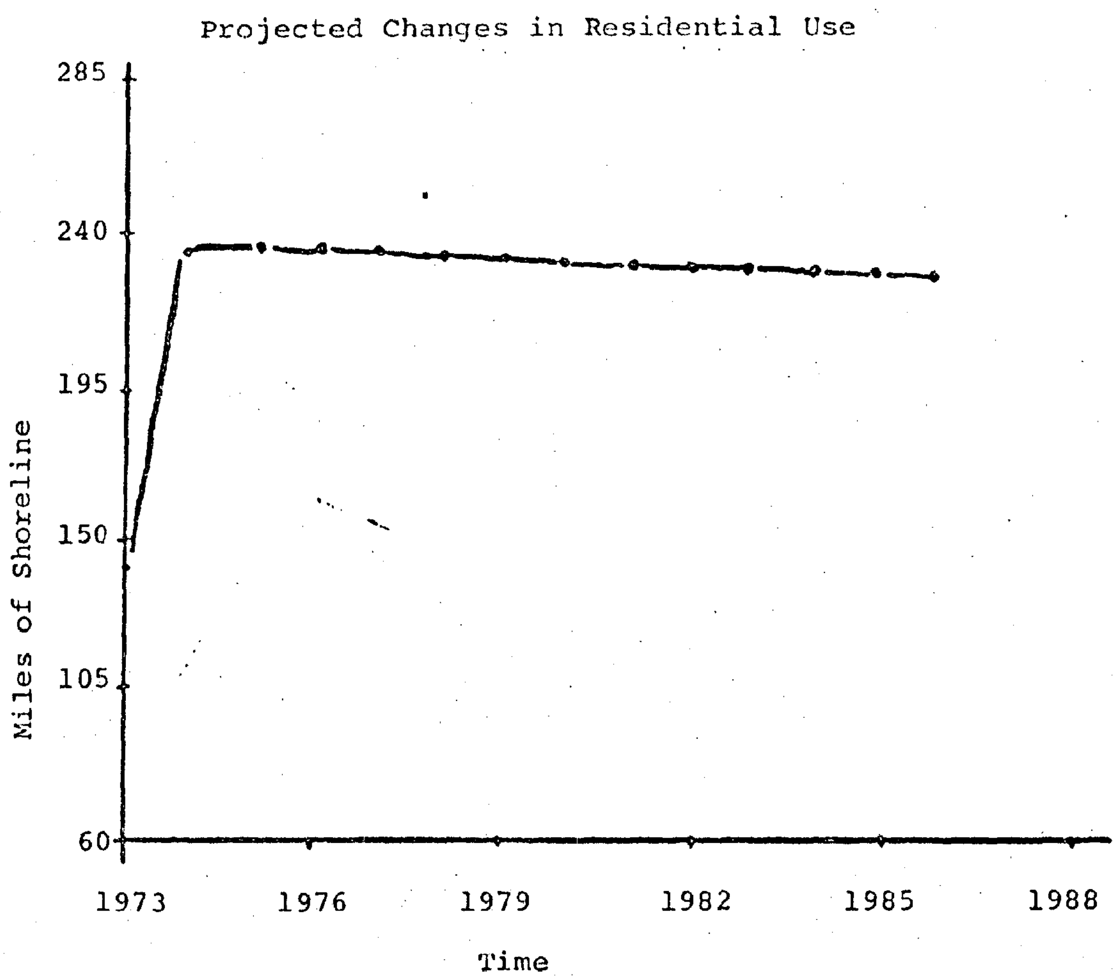
	RES	REC	NAT	CONR	SHDI	SHDC	TRAN	SHOC
($)	15	10	1	10	19	18	20	3
(1)	-0	-0	-0	-0	-0	-0	-0	1
(2)	1	0	0	1	0	1	1	1
(3)	0	1	0	0	0	0	0	0
(4)	-0	-0	1	-0	-0	-0	-0	-0
(5)	1	0	0	0	0	1	1	1
(6)	1	0	0	0	1	0	1	1
(7)	1	0	0	0	1	1	0	1
(8)	-0	-0	-0	-0	1	1	-0	-0

Table 13

THE OUTPUT GENERATED BY THIS PROGRAM CONSISTS
OF A TABLE PRESENTING VARIABLE VALUES THROUGH
TIME, AND ONE TO SEVERAL GRAPHS.

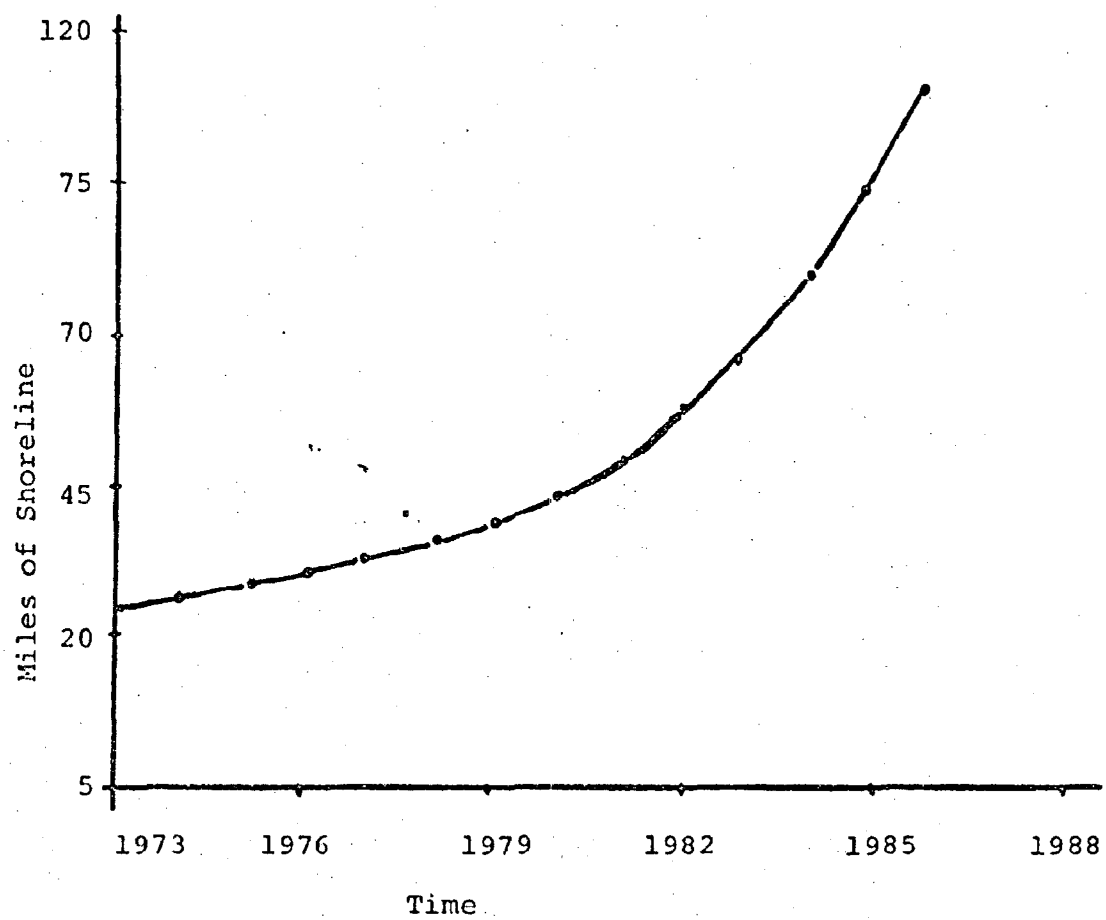
YEAR	RES	REC	NAT	CONR	SHDI	SHDC	TRANS	NSHD	FLDD
1973	143.4	26.5	413.0	527.5	8.1	5.4	4.1	94.3	
1974	237.5	27.7	413.0	526.4	8.1	5.5	4.2	.0	19061068
1975	237.3	29.1	413.0	524.9	8.1	5.6	4.2	0.0	19034116
1976	237.0	31.0	413.0	523.1	8.1	5.8	4.3	0.0	19000905
1977	236.7	33.3	413.0	520.8	8.1	5.9	4.5	0.0	18961966
1978	236.5	36.2	413.0	517.8	8.1	6.1	4.6	0.0	18917869
1979	236.2	39.9	413.0	514.2	8.1	6.2	4.7	0.0	18867245
1980	236.0	44.5	413.0	509.5	8.1	6.3	4.8	0.0	18806395
1981	235.8	50.4	413.0	503.7	8.1	6.5	4.9	0.0	18733010
1982	235.5	57.8	413.0	496.3	8.1	6.6	5.0	0.0	18644390
1983	235.3	67.1	413.0	487.0	8.1	6.8	5.1	0.0	18536887
1984	235.0	78.7	413.0	475.3	8.1	6.9	5.2	0.0	18405526
1985	234.8	93.4	413.0	460.7	8.1	7.0	5.3	0.0	18244091
1986	234.5	111.0	413.0	443.1	8.1	7.2	5.4	0.0	18053227

Graph 6


Projected Changes in Residential Use
285
240
195
150
105
60
Miles of Shoreline
1973
1976
1979
1982
1985
1988
Time

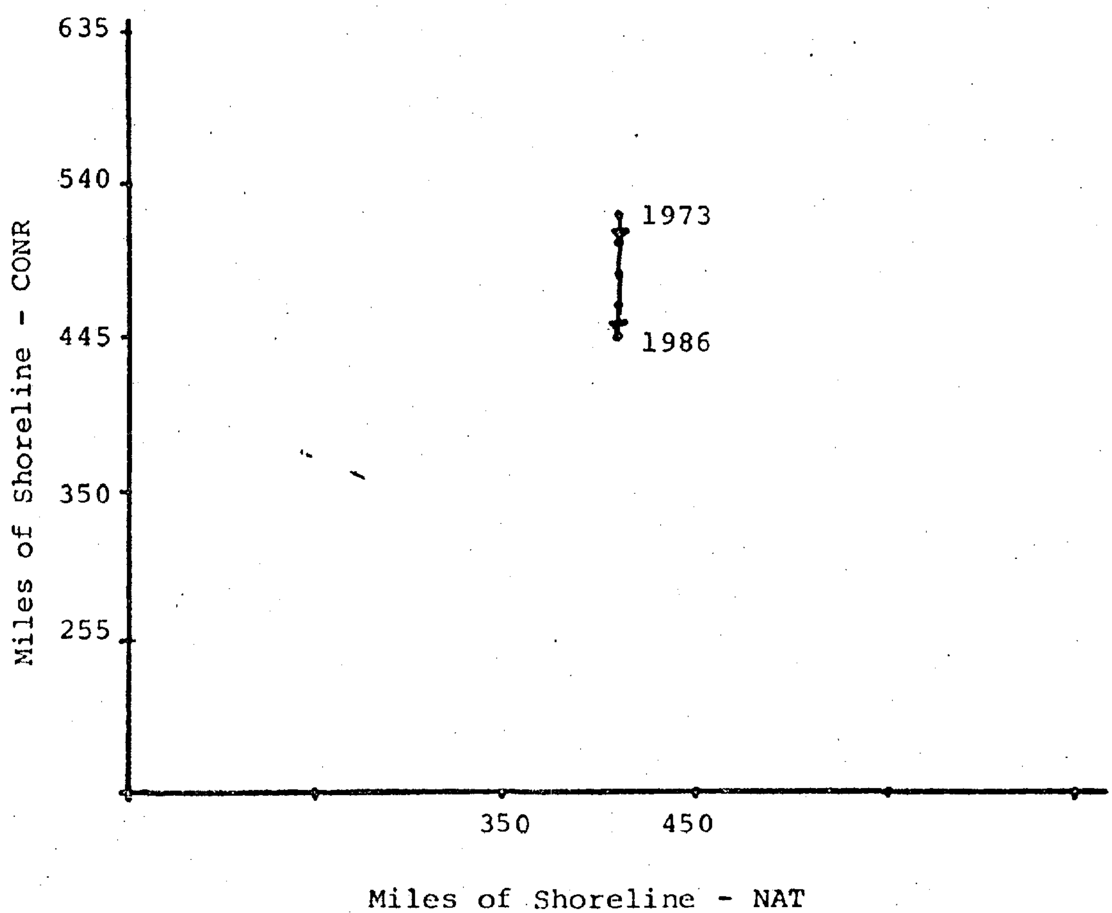
Graph 7

Projected Change in Recreational Use



Graph 8

Land Losses from NAT & CONR between 1973 & 1986



3. In the third example, the policy used reflects another conservation approach. Land is allowed to transfer into residential type from CONR indirectly: CONR into REC, REC into NAT, and NAT into RES. Again, the output and analytical graphs are presented below.

CALCULATION OF MILES OF SHORELINE BY CATEGORY

8 CATEGORIES CALC EVERY 1 YRS FROM YR 1973 FOR 13 YRS

Table 14

INPUT DATA

STATE AND COUNTY POPULATIONS

YEAR	STATE POP	COUNTY POP
1973	3738300	268500
1974	3832000	276700
1975	3925800	285000
1976	4019500	293300
1977	4113200	301500
1978	4206700	309800
1979	4300600	318100
1980	4394300	326300
1981	4499100	334600
1982	4604400	342900
1983	4709500	351100
1984	4814500	359400
1985	4919600	367700

INITIAL STATE VARIABLE VALUES

```
V-S: 143.4 26.5413.0527.5  8.1  5.4  4.1 94.3
DV-S:   7.2    .9 -0.5 -0.0 -0.0 -0.0 -0.0    .9
```

Table 15

RELATIVE DOLLAR VALUES AND ALLOWABLE TRANSFERS
CATEGORY

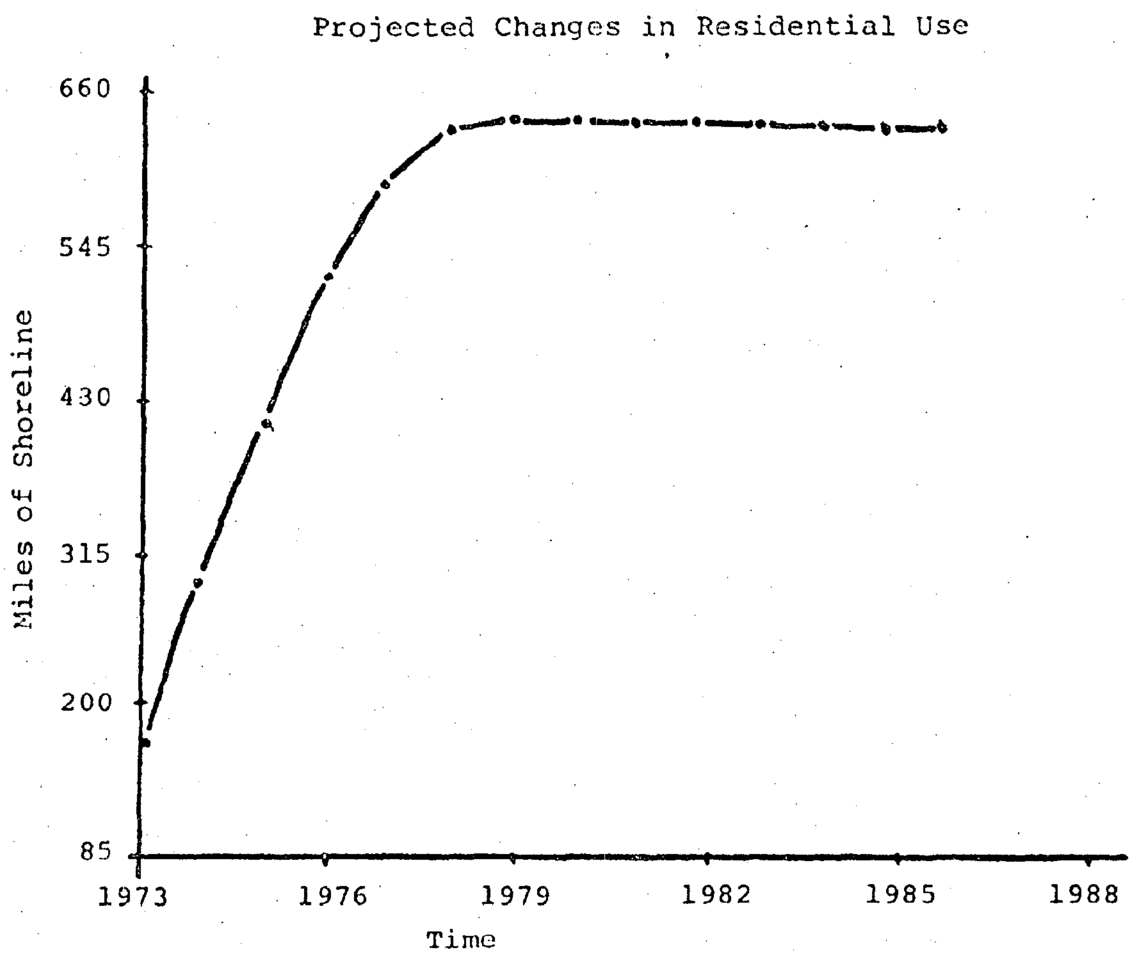
	RES	REC	NAT	CONR	SHOI	SHOC	TRAN	SHOC
($)	15	10	1	10	19	18	20	3
(1)	0	0	1	0	0	0	0	1
(2)	1	0	0	1	0	1	1	1
(3)	0	1	0	0	0	0	0	0
(4)	0	0	1	0	0	0	0	0
(5)	1	0	0	0	0	1	1	1
(6)	1	0	0	0	1	0	1	1
(7)	1	0	0	0	1	1	0	1
(8)	0	0	0	0	1	1	0	0

Table 16

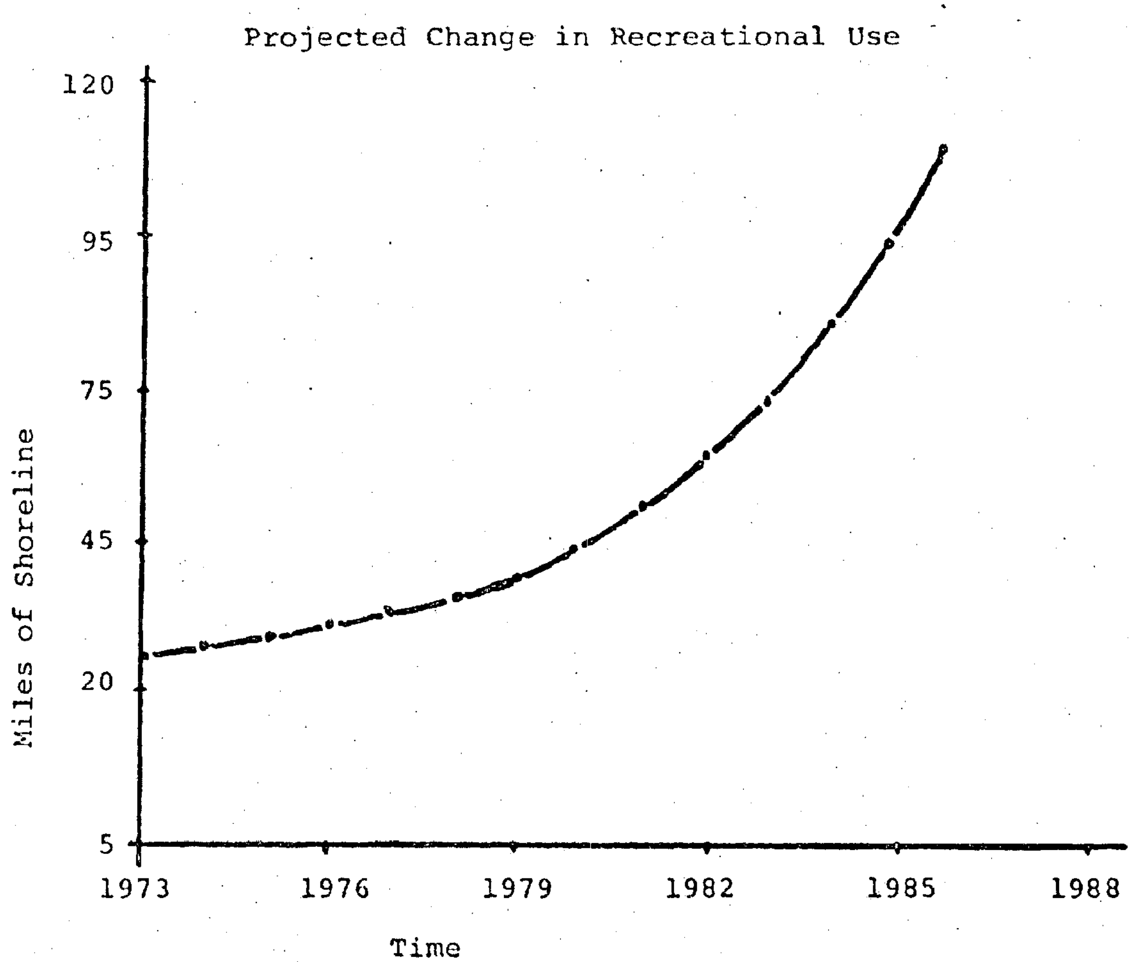
THE OUTPUT GENERATED BY THIS PROGRAM CONSISTS OF A TABLE PRESENTING VARIABLE VALUES THROUGH TIME, AND ONE TO SEVERAL GRAPHS.

YEAR	RES	REC	NAT	CONR	SHOI	SHOC	TRANS	NSHD	FLOD
1973	143.4	26.5	413.0	527.5	8.1	5.4	4.1	94.3	
1974	287.0	27.7	269.4	527.5	8.1	5.5	4.2	92.9	25664446
1975	410.2	29.1	146.2	527.5	8.1	5.6	4.2	91.3	32746177
1976	511.2	31.0	45.2	527.5	8.1	5.8	4.3	89.2	38526919
1977	593.6	33.3	0.0	527.5	8.1	5.9	4.5	49.4	41716357
1978	642.7	36.2	0.0	524.6	8.1	6.1	4.6	.0	42563277
1979	642.5	39.9	0.0	520.9	8.1	6.2	4.7	0.0	42512053
1980	642.3	44.5	0.0	516.2	8.1	6.3	4.8	0.0	42451803
1981	642.0	50.4	0.0	510.4	8.1	6.5	4.9	0.0	42375419
1982	641.8	57.8	0.0	503.0	8.1	6.6	5.0	0.0	42280793
1983	641.5	67.1	0.0	493.7	8.1	6.8	5.1	0.0	42192296
1984	641.3	78.7	0.0	482.1	8.1	6.9	5.2	0.0	[illegible]
1985	641.0	93.4	0.0	467.4	8.1	7.0	5.3	0.0	41889500
1986	640.8	111.0	0.0	449.8	8.1	7.2	5.4	0.0	[illegible]

Graph 9

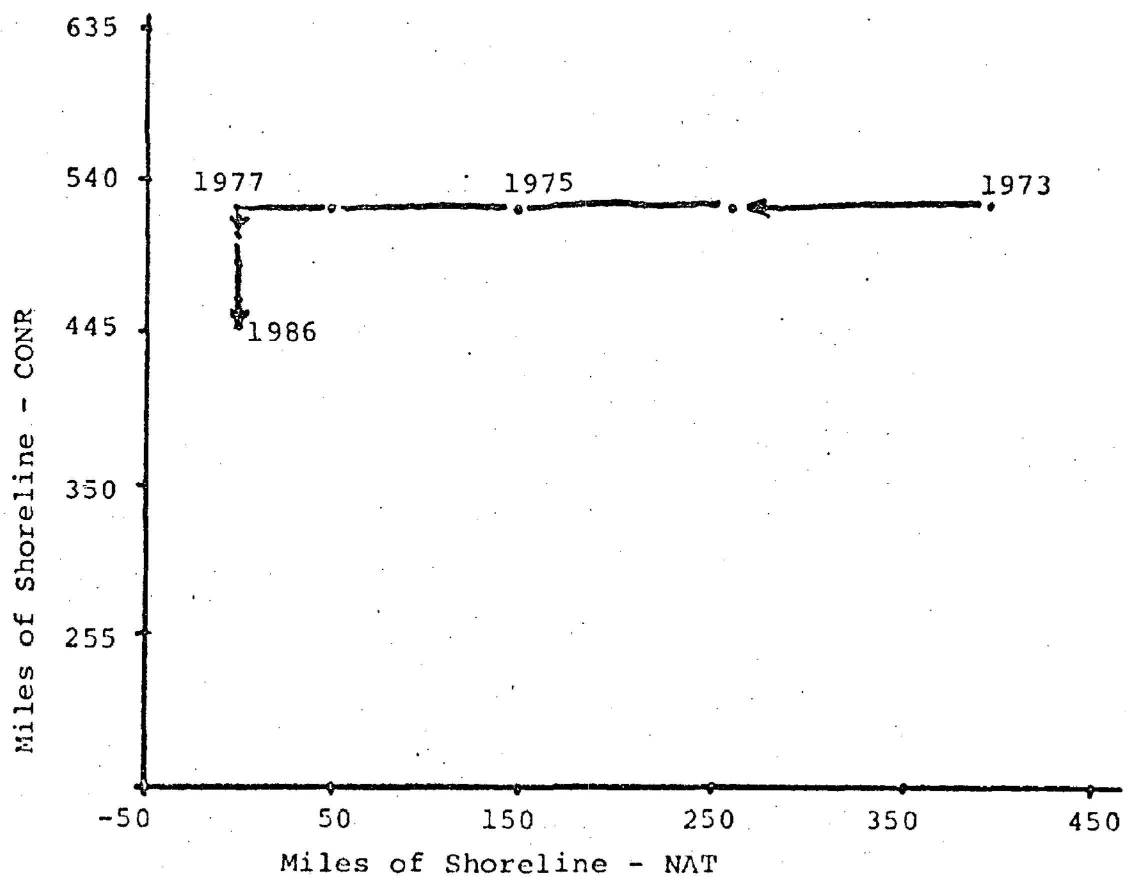

Projected Changes in Residential Use
660
545
430
315
200
85
Miles of Shoreline
1973
1976
1979
1982
1985
1988
Time

Graph 10


Projected Change in Recreational Use
120
95
75
45
20
5
Miles of Shoreline
1973
1976
1979
1982
1985
1988
Time

Graph 11

Land Losses from NAT & CONR between 1973 & 1986



V. Conclusion

Following the construction and exercising of Version 3 of the MACLUSE model, it was decided to temporarily cease the modeling effort and focus on a data-gathering project.

It was felt at this point that detailed land-use information of a historical nature was required to continue the modeling phase of the project in a meaningful manner. This was necessary for several reasons. First, a knowledge of what land use types are actually involved in a process of change is necessary to better define the primary system variables of the model. Second, historical data is required to isolate the important causal factors. Third, such data is necessary to fit model parameters and to provide a comparison to model results, thus making possible a good evaluation of the forecasting power of the model.

Toward this end, aerial photographs of the Snohomish County marine shoreline were obtained for the years 1947, 1955, 1965 and 1969. The analysis of this raw data set is to be carried out and will be described in a future paper. It is anticipated that the modeling effort will continue, although it may not take the exact form of further refinements of MACLUSE.